

2023



AP[®] Chemistry

Scoring Guidelines

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Question 1: Long Answer**10 points**

(a)(i) For the correct answer: **1 point**

Accept one of the following:

- $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^5$
- $[\text{Ar}] 4s^2 3d^5$

(ii) For the correct answer, consistent with part (a)(i): **1 point**

$4s$

Total for part (a) 2 points

(b) For the correct calculated value: **1 point**

$$62.673 \text{ g} - 61.262 \text{ g} = 1.411 \text{ g Cl}$$

(c) For the correct calculated value, consistent with part (b): **1 point**

$$1.411 \text{ g Cl} \times \frac{1 \text{ mol Cl}}{35.45 \text{ g Cl}} = 0.03980 \text{ mol Cl}$$

(d) For the correct answer, consistent with part (c): **1 point**

$$\frac{0.03980 \text{ mol Cl}}{0.0199 \text{ mol Mn}} = \frac{2 \text{ mol Cl}}{1 \text{ mol Mn}} \Rightarrow \text{MnCl}_2$$

(e) For the correct answer and a valid justification: **1 point**

Less than. If some of the mass of aqueous Mn_xCl_y is lost due to splattering, the final mass of the dry beaker and Mn_xCl_y will be decreased, which will decrease the calculated mass and number of moles of chlorine in the dry solid.

(f) (i)	For the correct balanced equation: $2 \text{MnO}_2(s) + \text{H}_2\text{O}(l) + 2 e^- \rightarrow \text{Mn}_2\text{O}_3(s) + 2 \text{OH}^-(aq)$ $\text{Zn}(s) + 2 \text{OH}^-(aq) \rightarrow \text{ZnO}(s) + \text{H}_2\text{O}(l) + 2 e^-$ $2 \text{MnO}_2(s) + \text{Zn}(s) \rightarrow \text{Mn}_2\text{O}_3(s) + \text{ZnO}(s)$	1 point
(ii)	For the correct calculated value, consistent with part (f)(i): $E_{\text{cell}}^{\circ} = 0.15 \text{ V} - (-1.28 \text{ V}) = 1.43 \text{ V}$	1 point
(iii)	For the correct calculated value, consistent with part (f)(ii): $\Delta G^{\circ} = -nFE^{\circ} = -\frac{2 \text{ mol } e^-}{1 \text{ mol}_{\text{rxn}}} \times \frac{96,485 \text{ C}}{1 \text{ mol } e^-} \times \frac{1.43 \text{ J}}{1 \text{ C}} \times \frac{1 \text{ kJ}}{1000 \text{ J}} = -276 \text{ kJ/mol}_{\text{rxn}}$	1 point
(iv)	For the correct answer and a valid justification: Accept one of the following: • <i>Disagree. The battery is enclosed, so no change in the <u>total</u> mass will occur.</i> • <i>Disagree. All reactants and products are in the solid phase, so the mass of the sealed battery will remain the same (no gases enter or exit the battery).</i>	1 point
		Total for part (f) 4 points
		Total for question 1 10 points

Question 2: Long Answer**10 points**

- (a) For the correct calculated value reported with the correct number of significant figures: **1 point**

$$1.25 \text{ mol AlCl}_3 \times \frac{3 \text{ mol Cl}}{1 \text{ mol AlCl}_3} \times \frac{35.45 \text{ g Cl}}{1 \text{ mol Cl}} = 133 \text{ g Cl}$$

- (b) For the correct algebraic manipulation of either ΔH_2° or ΔH_4° (may be implicit): **1 point**

Accept one of the following:

- Reversing reaction 2:



- Multiplying reaction 4 by $\frac{3}{2}$:



For the correct calculated value: **1 point**

$$\Delta H_1^\circ = -\Delta H_2^\circ + \Delta H_3^\circ + 1.5(\Delta H_4^\circ) = -(-583) + 326 + 1.5(243) = 1274 \text{ kJ/mol}_{\text{rxn}}$$

Total for part (b) 2 points

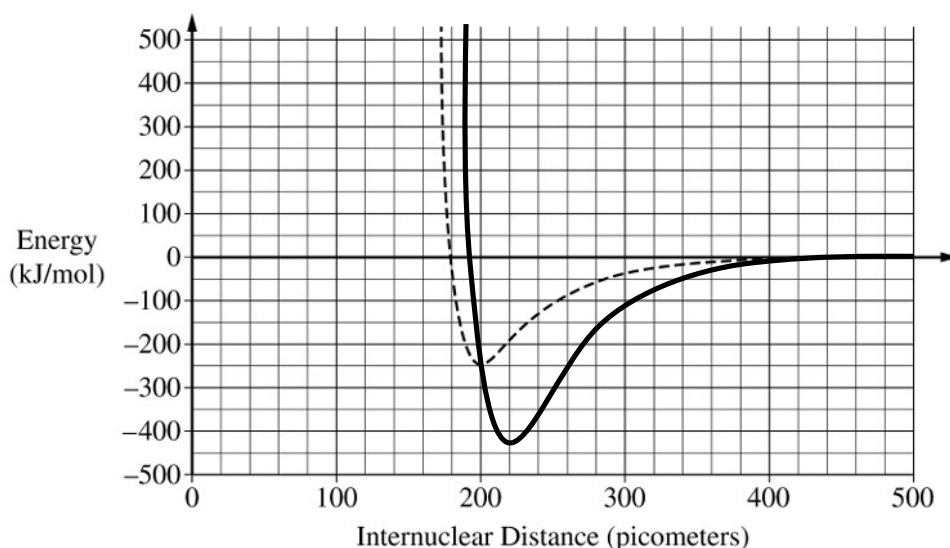
- (c) (i) For the correct answer: **1 point**

200 picometers ($\pm 10 \text{ pm}$)

- (ii) For a curve with a minimum at an internuclear distance of $220 \pm 10 \text{ pm}$: **1 point**

See sample curve below

For a curve with a minimum energy value of $-425 \pm 20 \text{ kJ/mol}$ that approaches zero as the internuclear distance approaches 500 pm: **1 point**



Total for part (c) 3 points

(d)(i) For the correct answer and a valid justification: **1 point**

Diagram 2. Al has four electron domains in Diagram 2, which would be trigonal pyramidal, not trigonal planar.

(ii) For the correct answer and a valid justification: **1 point**

Diagram 1. All atoms in diagram 1 have a formal charge of zero, whereas atoms in diagrams 2 and 3 have nonzero formal charges.

Total for part (d) 2 points

(e) For the correct answer: **1 point**

$$K_p = \frac{P_{\text{Al}_2\text{Cl}_6}}{(P_{\text{AlCl}_3})^2}$$

(f) For the correct calculated value, consistent with part (e): **1 point**

$$K_p = \frac{\chi_{\text{Al}_2\text{Cl}_6}(P_{\text{total}})}{(\chi_{\text{AlCl}_3}(P_{\text{total}}))^2} = \frac{\frac{3}{10}(22.1)}{\left(\frac{7}{10}(22.1)\right)^2} = 0.0277$$

Total for question 2 10 points

Question 3: Long Answer**10 points**

(a) For the correct balanced equation (state symbols not required): **1 point**

Accept one of the following:

- $\text{CaCO}_3(s) + 2 \text{H}^+(aq) \rightarrow \text{Ca}^{2+}(aq) + \text{CO}_2(g) + \text{H}_2\text{O}(l)$
- $\text{CaCO}_3(s) + 2 \text{H}_3\text{O}^+(aq) \rightarrow \text{Ca}^{2+}(aq) + \text{CO}_2(g) + 3 \text{H}_2\text{O}(l)$

(b) For a correct explanation: **1 point**

Accept one of the following:

- *Even though the concentration of HCl is greater in trial 5 than in trial 2, the reaction time is significantly longer. Both trial 2 and 5 occur under otherwise identical conditions. The trend for trial 1 and 4 indicates that the higher concentration of HCl results in a shorter time of reaction.*
- *The time of reaction in trial 5, with small chunks of calcium carbonate, is longer than trial 6 with large chunks. Both trial 5 and 6 occur under otherwise identical conditions. The trend for trials 1, 2, and 3 shows that larger chunks of the solid result in longer time of reaction.*

(c) For a correct explanation of the effect of surface area on reaction time: **1 point**

The time of reaction in trial 2 is shorter than that in trial 3 because the calcium carbonate in trial 2 has a larger surface area (meaning that more particles of calcium carbonate are exposed to the H^+ particles in the solution).

For a correct explanation of the effect of particle collisions on reaction rate: **1 point**

The larger interface between the two reacting substances means there will be more collisions between the particles in a given amount of time, and thus, a higher frequency of successful collisions in which the particles react to form the products.

Total for part (c) 2 points

(d) For the correct answer and a valid justification: **1 point**

Accept one of the following:

- *Disagree. If the reaction was zeroth order with respect to HCl, then changing the concentration of HCl would not affect the rate of reaction, and the time of reaction would be the same for trials in which the only difference was [HCl]. The student's data for trials 1 and 4 (likewise for 3 and 6) show that changing [HCl] significantly alters the time of reaction.*
 - *Disagree. The reaction appears to be first order, not zeroth order, with respect to [HCl]. Tripling [HCl] results in a reaction time that is 1/3 of that when [HCl] = 1.00 M, which means the reaction rate has also tripled, indicating a first-order process.*
-

(e) For the correct calculated moles of HCl reacted (may be implicit): **1 point**

$$1.00 \text{ g CaCO}_3 \times \frac{1 \text{ mol}}{100.09 \text{ g}} = 0.00999 \text{ mol CaCO}_3$$

$$0.00999 \text{ mol CaCO}_3 \times \frac{2 \text{ mol HCl}}{1 \text{ mol CaCO}_3} = 0.0200 \text{ mol HCl reacted}$$

For the correct calculated [HCl] remaining, consistent with the number of moles reacted: **1 point**

$$0.0500 \text{ L} \times \frac{1.00 \text{ mol HCl}}{1 \text{ L}} = 0.0500 \text{ mol HCl initially present}$$

$$0.0500 \text{ mol} - 0.0200 \text{ mol} = 0.0300 \text{ mol remaining}$$

$$\frac{0.0300 \text{ mol}}{0.0500 \text{ L}} = 0.600 \text{ M HCl remaining}$$

Total for part (e) 2 points

(f) For the correct answer and a valid justification: **1 point**

Exothermic. The solution temperature increases as the reaction proceeds.

(g)(i) For the correct calculated value (sign not required): **1 point**

$$q_{\text{surr}} = mc\Delta T = (51.0 \text{ g})(4.0 \frac{\text{J}}{\text{g}\cdot^\circ\text{C}})(21.90^\circ\text{C} - 21.20^\circ\text{C}) = 140 \text{ J}$$

(ii) For the correct calculated value, consistent with (g)(i), and the correct sign, consistent with (f): **1 point**

$$q_{\text{sys}} = -q_{\text{surr}} = -140 \text{ J} = -0.14 \text{ kJ}$$

$$1.00 \text{ g CaCO}_3 \times \frac{1 \text{ mol CaCO}_3}{100.09 \text{ g CaCO}_3} \times \frac{1 \text{ mol}_{\text{rxn}}}{1 \text{ mol CaCO}_3} = 0.00999 \text{ mol}_{\text{rxn}}$$

$$\Delta H_{\text{rxn}}^\circ = \frac{-0.14 \text{ kJ}}{0.00999 \text{ mol}_{\text{rxn}}} = -14 \text{ kJ/mol}_{\text{rxn}}$$

Total for part (g) 2 points

Total for question 3 10 points

Question 4: Short Answer**4 points**

(a) For the correct calculated value: **1 point**

$$0.00250 \text{ mol CH}_3\text{NH}_3\text{Cl} \times \frac{67.52 \text{ g}}{1 \text{ mol}} = 0.169 \text{ g}$$

(b) For a correct description of step 1: **1 point**

Accept one of the following:

- *Use the spatula, balance, and weighing paper to measure out exactly 0.169 g of CH₃NH₃Cl(s).*
- *Use the balance to weigh out the mass of solid in part (a).*

For a correct description of step 4: **1 point**

Rinse the buret with a small amount of 0.100 M CH₃NH₂(aq), drain, and refill with 0.100 M CH₃NH₂(aq).

Total for part (b) 2 points

(c) For the correct answer and a valid justification: **1 point**

Equal to. The ratio of weak acid to conjugate base is still 1:1.

Total for question 4 4 points

Question 5: Short Answer

4 points

- (a) (i) For the correct calculated value: 1 point

$$n = \frac{PV}{RT} = \frac{(7.45 \text{ atm})(6.00 \text{ L})}{(0.08206 \frac{\text{L}\cdot\text{atm}}{\text{mol}\cdot\text{K}})(296 \text{ K})} = 1.84 \text{ mol}$$

- (ii) For the correct calculated value: 1 point

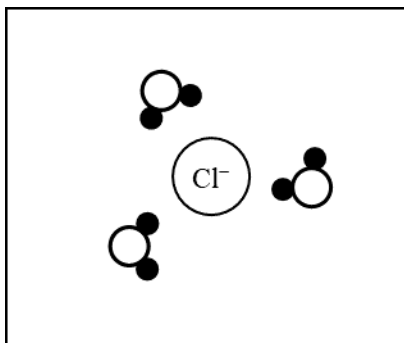
Accept one of the following:

- $\frac{P_1}{T_1} = \frac{P_2}{T_2}$
 $P_2 = \frac{(P_1)(T_2)}{T_1} = \frac{(7.45 \text{ atm})(271 \text{ K})}{296 \text{ K}} = 6.82 \text{ atm}$
- $P = \frac{nRT}{V} = \frac{(1.84 \text{ mol})(0.08206 \frac{\text{L}\cdot\text{atm}}{\text{mol}\cdot\text{K}})(271 \text{ K})}{6.00 \text{ L}} = 6.82 \text{ atm}$

Total for part (a) 2 points

- (b) For a correct drawing: 1 point

The drawing should show three water molecules with a hydrogen atom (dark circle) oriented towards the Cl^- ion.



- (c) For the correct answer and a valid justification: 1 point

HNO_2 . The diagram shows most of the molecules in their un-ionized form, indicating a weak acid with a K_a value less than 1, which is consistent with HNO_2 .

Total for question 5 4 points

Question 6: Short Answer**4 points**

(a) For the correct answer: **1 point**

HBr(l) : *London dispersion forces, dipole-dipole attractions*

HF(l) : *London dispersion forces, dipole-dipole attractions, hydrogen bonding*

(b)(i) For a correct explanation: **1 point**

$\Delta H_{\text{vap}}^{\circ}$ is greater for HF(l) than HBr(l) because the overall intermolecular forces in HF(l) are stronger than those in HBr(l) due to hydrogen bonding attractions present in HF(l), so more energy is required to separate the molecules in HF(l).

(ii) For the correct calculated value: **1 point**

$$6.85 \text{ g HF} \times \frac{1 \text{ mol}}{20.01 \text{ g}} \times \frac{25.2 \text{ kJ}}{1 \text{ mol}} = 8.63 \text{ kJ}$$

Total for part (b) 2 points

(c) For a correct explanation: **1 point**

Br has two additional occupied electron shells ($n = 3$ and $n = 4$) compared to F ($n = 2$). The extra electron shells increase the distance between the H and Br nuclei, giving HBr the greater bond length.

Total for question 6 4 points

Question 7: Short Answer**4 points**

(a) For a correct answer: **1 point**

Accept one of the following:

- *The student's drawing shows an incorrect ratio of Sr^{2+} and OH^- ions.*
- *The student's drawing is not charge-balanced.*

(b)(i) For the correct calculated value: **1 point**

$$\frac{0.043 \text{ mol Sr}^{2+}}{1 \text{ L}} \times \frac{2 \text{ mol OH}^-}{1 \text{ mol Sr}^{2+}} = 0.086 \text{ M OH}^-$$

(ii) For the correct calculated value, consistent with (b)(i): **1 point**

$$K_{sp} = [\text{Sr}^{2+}][\text{OH}^-]^2 = (0.043)(0.086)^2 = 3.2 \times 10^{-4}$$

Total for part (b) 2 points

(c) For the correct answer and a valid justification: **1 point**

Less than. Because the $\text{Sr}(\text{NO}_3)_2(\text{aq})$ solution already contains a common ion, $\text{Sr}^{2+}(\text{aq})$, the solubility of $\text{Sr}(\text{OH})_2$ will be decreased, resulting in a lower value of $[\text{OH}^-]$.

Total for question 7 4 points